DecSup: An Architecture Description Language for Specifying and Simulating the Decision Support System Architectures

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Abstract: Decision support systems (DSSs) have been existing for automating the decision making processes and reaching the optimum decision(s) using a data set in the quickest way. Despite the importance of DSSs, no any architecture description language (ADL) have been proposed for the high-level specifications and analysis of DSS architectures. So, in this paper, we propose a new ADL called *DecSup* which enables for the graphical specifications of DSS architectures in terms of the problem, diagnosis, and action components that interact with each other in an event-based manner. Problem components represent the domain data sets whose initialisation/change trigger an event for the diagnosis component. Diagnosis components include pattern predicates for making diagnosis using the events occurring. Whenever a diagnosis is made, another event is emitted for the action components to take any necessary actions. *DecSup* is supported with a prototype toolset for specifying the architecture models and transforming models in the Modelica simulation language. The transformed Modelica code can be used to simulate the DSS architecture models and test the architectural decisions via some scenarios. We evaluated *DecSup* using a case-study based on the contagious respiratory illnesses (i.e., cold, flu, and Covid-19).

1 INTRODUCTION

Architecture description languages (ADLs) have been existing since the early nineties for enabling the high-level specifications of software architectures (Garlan and Shaw, 1994; Perry and Wolf, 1992). With ADLs, high-level architectural design decisions can be specified and reasoned about in the early design stage so as to better analyse the requirements and thus lead the development of quality software systems (Ozkaya, 2018b; Clements, 1996; Medvidovic and Taylor, 2000). Some ADLs are supported with tools, through which architectural decisions can be analysed, simulated, proved for correctness, checked for quality properties (e.g., performance, reliability, and security), and further transformed into code.

ADLs may differ depending on their scope - general-purpose ADLs and domain-specific ADLs (Taylor et al., 2010). General-purpose ADLs (e.g., Wright (Allen and Garlan, 1997), Darwin (Magee and Kramer, 1996), XCD (Ozkaya and Kloukinas, 2014), etc.) offer general-purpose notation sets for specifying the architectures of any types of software systems, while domain-specific ADLs (e.g., AADL (Feiler et al., info)) support the architectural specifications of systems at particular domains (e.g., the embedded systems domain). With domain-specific ADLs, it becomes possible to address any issues specific to a particular problem domain at an architectural level and perform further operations such as analysis, simulation, code generation, etc.

In this study, a novel domain-specific ADL is proposed for the high-level specifications of decision support system (DSSs) architectures. DSSs are intended for enabling the computers to make decisions for any given problems by using the existing data (Holsapple, 2008; Alexander, 2002). Today, DSSs are used in almost all the industries to automate the decision making processes including healthcare, finance, manufacturing, defense, railway, and disaster management, etc. While the number of DSS tools has been ever-increasing, the DSS tools developed may not be the one desired by the domain experts, as it is likely for the developers to get the requirements in an incomplete, incorrect, or inconsistent way (Humphrey, 2006; Charette, 2005; Hussain

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and Mkpojiogu, 2016). Also, inadequate handling of the requirements and architectural design stages lead to the issue called architectural mismatch (Garlan et al., 1995), which causes the inability of composing a set of components to a successful system due to the wrong assumptions made about the interactions and behaviour of the components.

Despite many ADLs existing in the literature which focus on different domains and problems, no ADL supports the specifications of high-level DSS architectures and their reasoning as discussed in Section 2. None of the existing ADLs provide a specific architectural notation set that can be suited for the DSS architecture modeling. Therefore, we propose in this paper a new ADL called *DecSup* for specifying the DSS architectures and a prototype toolset for demonstrating our language and performing the analysis and simulation of DSS architecture models. With *DecSup*, DSS architectures can be specified in terms of the problem, diagnosis, and action components that can interact with each other in an event-based manner. The DSS architectures specified with *DecSup* can automatically be transformed in accordance with the Modelica simulation language (Fritzson, 2004)[1], and the transformed *Modelica* models can be simulated via the simulators supporting Modelica[2].

In the rest of the paper, we firstly discuss the similar languages in the literature. Then, we introduce the language definition and the tool support for *DecSup* subsequently. Next, we introduce our case study that we intend to use for evaluating the language and its toolset. Lastly, we give the conclusion.

2 RELATED WORK

In the literature, many ADLs have been proposed, each of which has contributed to the field on different aspects with some interesting features. We discussed several of those ADLs in our previous work in terms of a comprehensive set of requirements that are categorised as the language definition, language features, and tool support (Ozkaya, 2018b). In other works, we further analysed domain-specific modeling languages including the UML-based modeling languages (Ozkaya, 2018a) and IoT-based modeling languages (Arslan et al., 2023). However, while there exist some languages that support the decision making processes in some particular domains, none of the existing languages support the high-level specifications of DSS architectures regardless of any problem domains and the simulation of the high-level design decisions.

[1]Modelica web-page: https://modelica.org/

[2]Modelica simulators: https://modelica.org/tools.html

Besides the ADLs, the literature also includes some meta-modeling approaches that promote the application of model-driven engineering for the decision making processes and propose a set of concepts and relationships specific to particular domains (e.g., disaster management, manufacturing, healthcare, and software cost estimation) (Othman and Beydoun, 2013; Porres et al., 2008; Almeida et al., 2021; Weston, 2012). However, those approaches do not propose a language with concrete notation set. Also, none of those approaches focus on the high-level specifications of DSS architectures regardless of any domain concerns and their simulation.

The literature further includes event processing languages (EPLs), through which the events representing the domain data can be specified and composed to more complex events using event patterns (Boubeta-Puig et al., 2014). Event patterns can be used for making any diagnosis based on the events gathered from the environment. EPLs can be stream-based or rule-based and supported by the tools that can transform models into executable event-driven applications (e.g., the Esper[3] stream-based language and the Drools Fusion[4] rule-based language). However, EPLs do not aid in specifying the DSS architectures in terms of a specific set of component and connector types as is the case with our DecSup ADL.

3 DecSup'S DEFINITION

To define the concepts for DecSup, we got inspired from Dunkel et al.'s work on proposing a reference architecture for the event-driven DSSs (Dunkel et al., 2011). Figure 1 depicts the meta-model diagram for DecSup, which shows the concepts corresponding to the architectural component and connector types, the attributes that those types are composed of, and the multiplicity constraints. So, the language definition consists of three types of main components (i.e., problem, diagnosis, and action) and two types of connectors (problem-to-diagnosis and diagnosis-to-action).

3.1 Problem Component Type

We consider each DSS as addressing some problems and requiring problem-related data from their environment so that the DSS can determine the occurrence of the problem, make some diagnosis and take any necessary actions. The *Problem* component type here

[3]Esper: https://www.espertech.com/esper/

[4]Drools Fusion: https://docs.drools.org/5.6.0.Final/drools-fusion-docs/html/

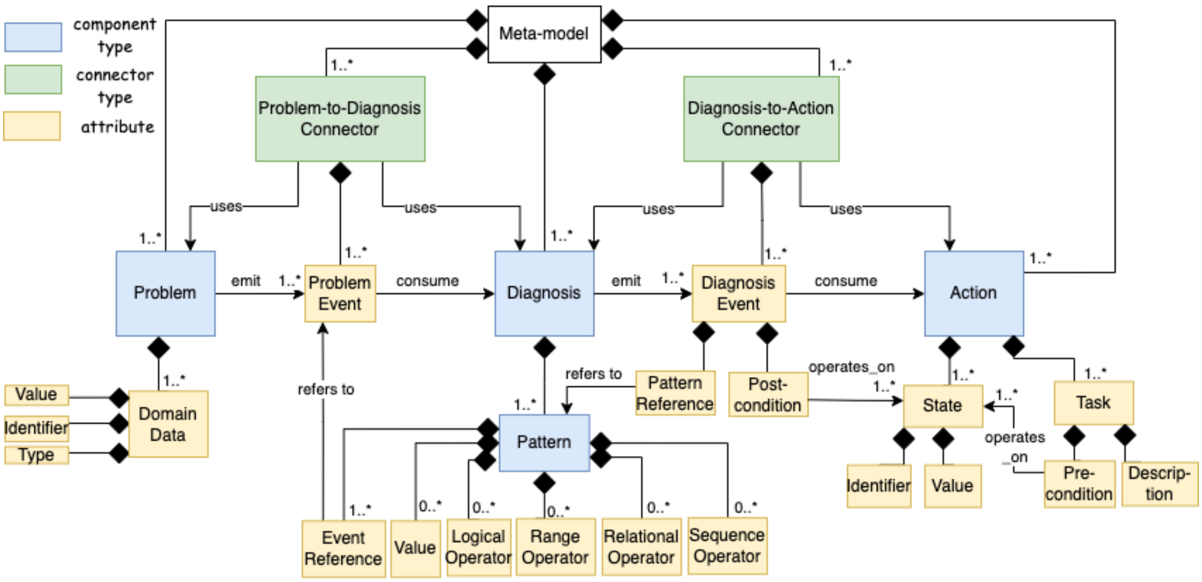


Figure 1: DecSup's meta-model diagram.

is used for specifying the domain data set for an existing problem. Note that any DSS architecture may include multiple components of the problem component type, each of which is concerned with a particular problem that the DSS considers for its decisions.

A problem component is composed of one or more domain data variables, which are specified with a data type (e.g., int and boolean), identifier, and data value. Note that as discussed in Section 3.4, whenever a data variable is initialised or get its value changed, this triggers an event to be occurring and emitted by a diagnosis component. An event triggered here conveys the data value of the associated data variable.

Figure 2 shows the use of DecSup's graphical notation set for specifying a problem component. Any problem component is specified with a red circle ("P"). Whenever the problem component symbol is clicked, a dialog box opens for specifying *(i)* the problem identifier, *(ii)* informal description text, and *(iii)* the domain data list. Whenever any domain data in the data list is clicked, a new user interface opens for specifying the type, identifier and value of the data.

3.2 Diagnosis Component Type

Whenever any problem occurs that lead to a set of domain data variables assigned with new/changed values, a diagnosis needs to be made using those data. A *Diagnosis* component type is for specifying the diagnosis descriptions and pattern predicates that are used for making detections from the problem data available. Any DSS architecture may consist of one or more diagnosis components each of which is concerned with a cohesive set of detections.

Any diagnosis component is composed of one or more pattern components. A pattern component type herein is used for specifying a pattern model that describes a predicate statement whose satisfaction (e.g., evaluating to *true*) indicates a diagnosis made from the problem(s) and triggers an event for an action.

A pattern model is specified with one or more event references that refer to the events generated by the problem components. Note here that each event used in a pattern model is essentially the representation of a domain data variable that is initialised and gets their value changed. The event references are used for comparing their data variables with some values using relational operators (e.g., greater than, less than, equal) or range operator (i.e., checking any event data is within a particular range). The comparison statements of different events are logically composed using logical operators (i.e., *AND*, *OR*, and *NOT*). A pattern may also check for the sequencing of events, such that the occurrence of one event can be dependent on the occurrence of another event.

Figure 3 shows DecSup's graphical notation set for specifying a diagnosis component. Any diagnosis component is specified with a green circle ("D"). Whenever the diagnosis component symbol is clicked, a dialog box opens for specifying *(i)* the component identifier, *(ii)* any description text, and *(iii)* a pattern component list. Whenever a pattern component in the list is clicked, a new sub-editor opens for specifying the graphical model that describes the pattern predicate. The pattern specification notation set here consists of basically the logical operator symbols

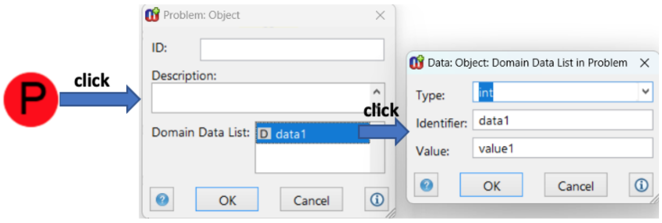


Figure 2: Problem specification in DecSup.

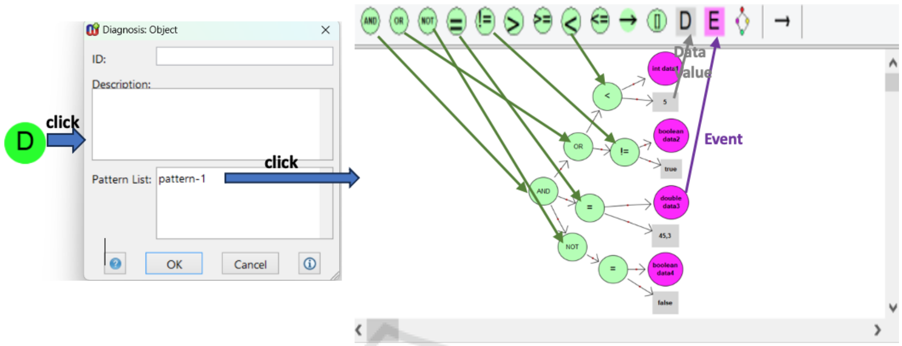


Figure 3: Diagnosis and pattern model specifications in DecSup.

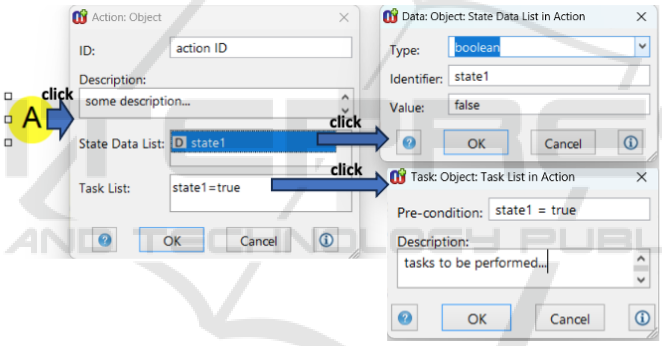


Figure 4: Action specification in DecSup.

(*AND, OR, NOT*), the relational operator symbols (=, <, >, ! =, <=, >=), event reference symbol (i.e., “E”), and data value symbol (“D”).

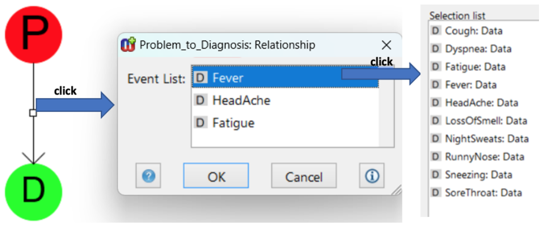
3.3 Action Component Type

Whenever any diagnosis pattern predicate evaluates to *true*, some action is expected to be operated. An *Action* component type is for specifying the action descriptions, which is composed of one or more state variables and task elements. A state variable represents a particular state that the action component can be in when the associated diagnosis pattern is satisfied. Each state variable is specified with a data type (e.g., int, boolean, and string), identifier and initial value. A task element represents the task(s) that needs to be performed assuming that the action component is in a particular state (i.e., the pre-condition is satisfied). A task element is therefore specified with a pre-condition on the state variables and a task description.

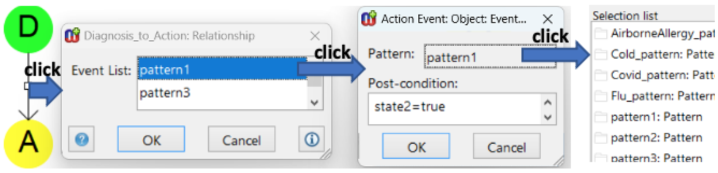
Figure 4 shows DecSup’s graphical notation set for specifying an action component. An action component is specified with a yellow circle (“A”). Whenever the action component symbol is clicked, a dialog box opens for specifying *(i)* the action identifier, *(ii)* any description text, *(iii)* the state list, and *(iv)* task list When the state list area is clicked, a new user interface opens for specifying a state variable. When the task list area is clicked, again a new user interface opens for specifying a task.

3.4 Problem-to-Diagnosis Connector Type

Any connector of the problem-to-diagnosis connector type is used to connect one problem component



(a) The problem-to-diagnosis connector specification.



(b) The diagnosis-to-action connectors specification.

Figure 5: Specifying connectors in DecSup.

with one diagnosis component so as to specify that any event occurring due to the problem component is consumed by the connected diagnosis component. A problem-to-diagnosis connector is composed of one or more events. An event here represents the occurrence that a domain data variable possessed by the problem component has got a new value assigned and thus the diagnosis component can be notified.

Figure 5a shows the directed arrow notation for the connector, which goes from the problem component to the diagnosis component. Whenever the connector arrow is clicked, a dialog box opens for specifying the connector events. Each event is specified by selecting a problem domain data variable from a list opening upon clicking the event list area on the dialog box. Note that the list opening here consists of the domain data variables of the problem component that the connector associates with.

3.5 Diagnosis-to-Action Connector Type

A connector of the diagnosis-to-action connector type is used to connect one diagnosis component with one action component so as to specify that any event occurring due to the diagnosis component is going to be consumed by the connected action component. A diagnosis-to-action connector is composed of one or more events. An event here represents the occurrence that a pattern predicate that is specified as part of the connected diagnosis component is evaluated to be true and thus the connected action component can then be notified accordingly. Each event here is specified with a reference to an existing diagnosis pattern and a post-condition statement. The post-condition statement represents the state(s) of the action that need(s) to be changed (e.g., assigned "true") upon the occurrence of the event (i.e., the pattern satisfaction). By doing so, the task(s) whose pre-condition on the action state are satisfied can get enabled by the action component due to the occurrance of the event.

Figure 5b shows the directed arrow notation for the connector, which goes from the diagnosis component to the action component. Whenever the connector arrow is clicked, a dialog box opens for viewing the event list. If the event-list area is clicked, a new user interface opens for specifying an event in terms of its pattern reference and post-condition.

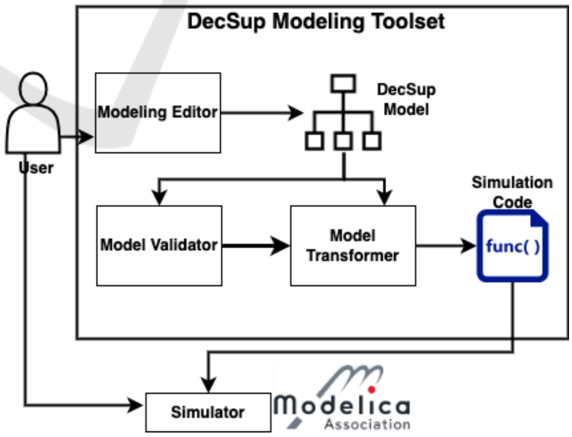


Figure 6: DecSup's Modeling Toolset Architecture.

4 TOOL SUPPORT

We developed a prototype modeling toolset for *DecSup* using the Metaedit+ meta-modeling technology

(Kelly et al., 2013)[5]. Figure 6 shows the tool architecture for the *DecSup* modeling toolset. The modeling toolset consists of a modeling editor, model validator, and model transformer. The toolset source files are available via our research group web-site[6].

Figure 7 shows the two different modeling editors supported by the modeling toolset - one for the DSS architecture modeling (left) and another for the pattern modeling that is accessed through the diagnosis component as depicted in Figure 3 (right). Each editor has a *(i)* toolbar where the graphical symbols can be dragged and dropped on the modeling area and *(ii)* a warning area where the model validation results are displayed at modeling time. Also, the editor for the DSS modeling includes a link at the top, which can be clicked for running the model transformer that transforms the model into the Modelica code.

The model validator here checks any DSS models for a set of pre-defined properties to ensure that the models are specified correctly with regard to the meta-model definitions and completely (i.e., not suffering from any missing information). Some of the the validation properties that are checked at modeling time automatically are *(i)* any identifiers (e.g., the identifiers for the components and data variables) or statements (e.g., task pre-condition and event post-condition) that are unspecified, *(ii)* any event that is used as part of the diagnosis pattern model but has not been specified as part of the event list of the associated problem-to-diagnosis connector, *(iii)* any event that is created for the event list of a problem-to-diagnosis connector but has not been associated with any domain data of the connected problem component, and *(iv)* any event that is used for a diagnosis-to-action connector but has not been associated with one of the patterns of the connected diagnosis component.

The model transformer here takes any valid DSS architecture model and transforms the model into the simulation code in Modelica. By doing so, the simulators that support Modelica can be used to simulate the DSS models and execute any test cases. That is, users can provide some inputs to the simulator and observe if the simulator that executes the architectural model produces the correct output or not.

5 CASE STUDY - CONTAGIOUS RESPIRATORY ILLNESSES

To demonstrate the use of the *DecSup* language and its toolset, we considered a case-study from the healthcare industry. We used the article published by National Institutes of Health (NIH) - i.e., part of the U.S. Department of Health and Human Services - for the contagious respiratory illnesses (i.e., cold, flu, airborne allergy, and Covid-19)[7]. NIH indicates a set of symptoms from which the cold, flu, airborne allergy, and Covid-19 diagnoses can be made. NIH also suggests treatments for each diagnosis.

5.1 Architecture Specification in DecSup

We used *DecSup* to specify the high-level architecture of a DSS that can make correct diagnosis of the contagious respiratory illness using the data produced and offer the correct treatment as described by NIH. The architecture specification in *DecSup* is as depicted in Figure 8. The full specification can be found via our research group web-site[6].

Problem Component. To specify the problem component, we determined the domain data that are needed for the diagnosis of the contagious respiratory illnesses. As depicted in Figure 8, the problem component consists of a number of domain data variables corresponding to the symptoms indicated by NIH. These are *fever, headache, general-aches, fatigue, exhaustion, runny-nose, sneezing, sore-throat, cough, chest-discomfort*, and *loss-of-smell-taste*.

Diagnosis Components. As depicted in Figure 8, four diagnosis components are specified - *Cold, Flu, Airborne Allergy*, and *Covid-19*. All those components are connected with the same problem component via separate connectors. The connector that connects *Cold* with the problem component includes an event for each problem domain data - except *extreme-exhaustion*. The connector that connects *flu* with the problem includes an event for each problem data. The connector that connects *airborne allergy* with the problem includes an event for each problem data - except *fever*, *general-ache*, and *extreme-exhaustion*. The connector that connects *Covid-19* with the problem includes an event for each problem domain data.

Each diagnosis component has one pattern model. In Figure 9, the pattern model specified for the *airborne allergy* diagnosis component is depicted. In the pattern model, we used a set of events indicated with the pink ellipse notation and each event corresponds to a unique domain data variable of the problem component that the diagnosis component is connected in Figure 8. The pattern model here is the logical *AND* composition of multiple equality operations

[5] Metaedit+ web-site: https://metacase.com/

[6] Our research group web-site:http://serg.yeditepe.edu.tr

[7] NIH web-site: https://newsinhealth.nih.gov/2022/01/it-flu-covid-19-allergies-or-cold

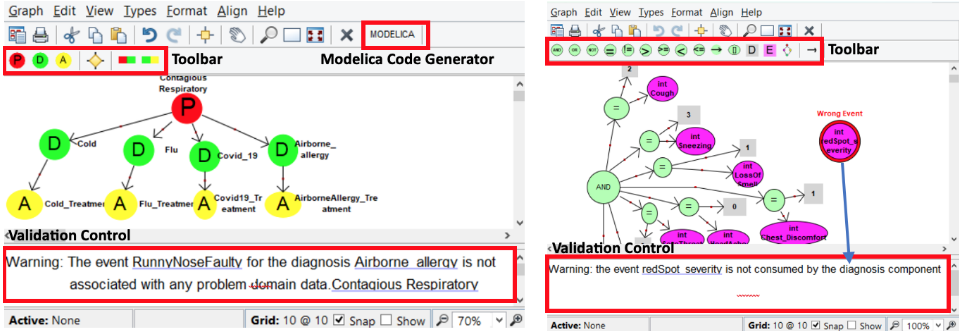


Figure 7: DecSup's editor support for the model specification, validation, and transformation.

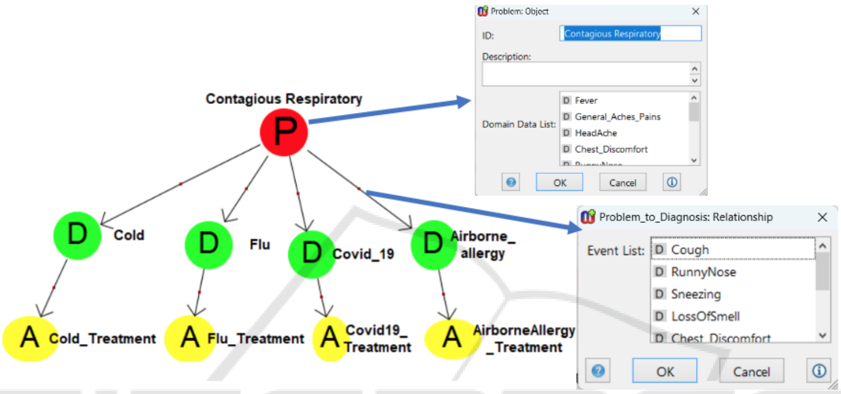


Figure 8: Specifying the DSS architecture for the contagious respiratory illnesses in DecSup.

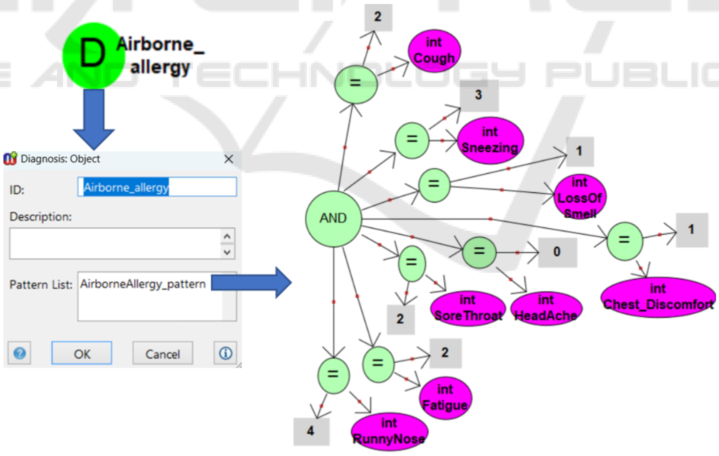


Figure 9: Specifying the pattern model for the airborne-allergy diagnosis component in DecSup.

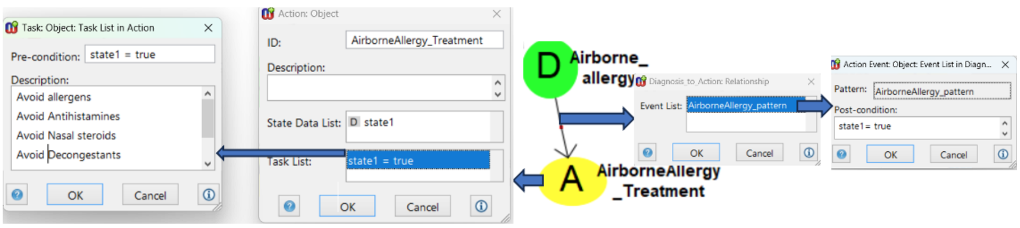


Figure 10: Specifying the airborne-allergy action component and its connector in DecSup.

each of which checks if the event data is equal to some value. Note that for simplicity, we consider here the data "uncommon" described by NIH[7] as the numeric value "0", "rare" as "1", "sometimes" as "2", "usual" as "3", and "common" as "4".

Action Components. As depicted in Figure 8, each diagnosis component is connected with one action component by means of the diagnosis-to-action connectors. Figure 10 shows the connector that connects the *airborne allergy* diagnosis component with the *airborne allergy treatment* action component. Whenever the connector herein is clicked, the dialog box opens for the event specifications. The only connector event herein is specified with *(i)* a reference to the pattern specification given in Figure 9 and *(ii)* a post-condition that asserts the *state1* state variable of the *airborne allergy treatment* action component to be *true*. The task specified for the *airborne allergy treatment* action here is taken into consideration when *state1* holds *true* (pre-condition).

5.2 Simulating the DecSup Specifications Using Modelica

We used the *DecSup* modeling toolset and transformed the DSS architecture specifications for the contagious respiratory illness that are discussed in the previous sub-section in Modelica.

Auto-generated Simulation Code. The transformed Modelica code includes a separate *Model* definition[8] (i.e., the basic building block in Modelica) for each component of the diagnosis and action types. The model definition for a diagnosis component basically consists of *(i)* an input connector statement[8] for each event specification through which the problem domain data are received and *(ii)* an algorithm section[8] for executing the pattern model specifications of the diagnosis component. The model definition for an action component consists of *(i)* an input connector statement for each event specification through which the notifications can be received indicating that the pattern predicate for that event specification is satisfied, *(ii)* the data variables corresponding to the state of the action component, and *(iii)* an algorithm section for changing the state variables in accordance with the the post-condition of any event occurring and printing out the descriptions of the tasks whose pre-conditions get satisfied upon the state data being changed with the event post-condition statements. Also, the transformed Modelica code includes another model definition that represents the entire architecture as specified in the *DecSup* model. The model definition this time includes *(i)* the instances of the other model definitions that correspond to the diagnosis and action components and their connections with each other as specified in the *DecSup* model, and *(ii)* the connections of the problem domain data variables with the diagnosis components. Note that those problem domain data variables can be assigned values during the simulation manually for testing purposes.

Simulation Process with OpenModelica. The transformed Modelica code can be simulated with any simulators that accept Modelica. We used the open-source OpenModelica simulator (Fritzson et al., 2006)[9] as depicted in Figure 11.

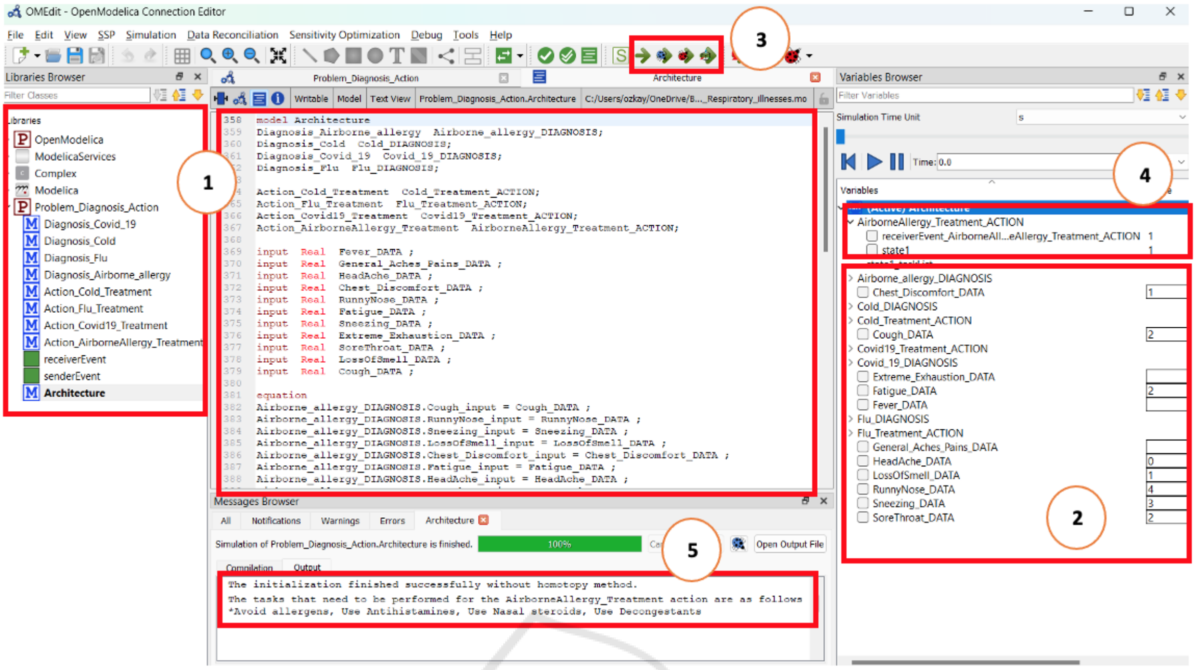
Before starting the simulation process, we firstly determined some test scenarios each of which consists of a concrete problem domain data set (i.e., the assignment of values to the problem domain data variables), an expected diagnosis, and an expected treatment. In Figure 11, we considered simulating the design decisions about the *airborne-allergy illness* that are specified and discussed in Section 5.

When we imported the transformed Modelica code into OpenModelica, the code structure is displayed on the simulator (see the red-box "1" in Figure 11). To start the simulation, we assigned the concrete values of the problem domain data variables between 0-4, where 0 represents "uncommon", 1 represents "rare", 2 represents "sometimes", and 3 represents "usual", 4 represents "common". As shown in Figure 11 (see the red-box "2" on the right-most side), the problem domain data variables appear with a box next to them through which the values can be entered. Then, we clicked to run the simulation (see the red-box "3") with those concrete data set so as to observe the diagnosis and the action taking place and compare those with the expected ones in our scenario.

To better understand the simulation results and test if the expected action is taken given a particular set of problem data, the action variables (those with "_ACTION" postfix) existing in the transformed Modelica code can be searched using the OpenModelica simulator (see the red-box indicated with "4" in Figure 11). Whenever any action is activated given the associated diagnosis is made, the respective action variable is assigned with "1". Also, the transformed Modelica code includes a separate variable for each state variable specified as part of the action component and those variables need to be changed as specified in the post-condition of the events occurring (see Section 5.1). As observed in Figure 11 (see the variable window indicated with the red-box "4" on the right), the action variable for the airborne-allergy is set as "1" and the state variable of the airborne-

[8] Modelica language user guide: https://specification.modelica.org/maint/3.6/MLS.html

[9] OpenModelica web-site: https://openmodelica.org/



1- The Modelica source files and the code editor, 2- User assigning the problem domain data, 3- Running the simulation, 4-Users observing the action that gets activated, 5- Users observing the tasks to be performed when an action is activated

Figure 11: Model simulation using OpenModelica.

allergy action component (i.e., *state1*) is set as "1" as the post-condition in Figure 10 asserts so. When the action state has been changed in accordance with the post-condition, then the action tasks whose pre-condition evaluates to true can be performed (see Figure 10). The descriptions of those activated tasks are displayed in the message browser part of the simulator user interface (i.e., red-box "5" indicated at the bottom part in Figure 11).

6 CONCLUSION

In this paper, we introduce a novel architecture description language called *DecSup* for the high-level specifications of DSS architectures and their simulation. *DecSup* offers a graphical notation set for specifying the DSS architectures in terms of problem, diagnosis, and action components that interact with each other in an event-based manner. Problem components represent the domain data set about the decision making process. The diagnosis components receive event notifications from the problem component(s) that they are connected with whenever the problem domain data that the diagnosis components are interested in change (or get initialised). Then, the diagnosis components process their pattern predicates that are each specified as a separate model. If the pattern predicate of a diagnosis component is satisfied, the action component that is connected with the diagnosis component and interested in the pattern result is notified with an event. The action component then gets their particular state(s) changed in accordance with the event post-condition. Lastly, the action component can operate any of its tasks whose pre-condition on the action state get(s) satisfied with the state changes.

DecSup is supported with a prototype modeling toolset, which consists of a modeling editor, model validator and model transformation tool. Any *DecSup* models specified with the editor can be checked for some validation properties at modeling time automatically. The valid models can be transformed into Modelica, which is a modeling language that is supported by many simulators including the open-source OpenModelica simulator.

We evaluated *DecSup* and its toolset using a case-study that is based on the contagious respiratory illnesses which has been inspired from the article published by the National Institutes of Health (NIH). We used *DecSup* to *(i)* specify the DSS architecture for the contagious respiratory illnesses, *(ii)* validate the modeling errors for correctness and completeness, and *(iii)* simulate the model using OpenModelica via some test scenarios and check if the correct diagnosis is made and the correct actions are taken given some sample problem data.

In the future, we are planning to evaluate our approach with a number of case-studies from different problem domains including healthcare, disaster management, and logistics. We will also extend our modeling toolset with a code generator, which can produce a decision making software in accordance with the architectural design decisions specified in *DecSup* using the open-source event stream processing framework called Esper[3].

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